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FIRE TESTS OF ADVANCED ARAMID BLENDS AND TREATMENTS

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FULL SCALE FUEL FIRE PIT TESTS WERE PERFORMED ON THREE DIFFERENT GROUPS OF FLIGHT SUITS. THE PURPOSE OF THESE TEST WAS TO COMPARE THE FIRE PROTECTIVE QUALITY, AS RELATED TO PERCENT BODY BURNED, OF SUPER FLAME-RESISTANT NOMEX BLENDS. THE MATERIALS TEST WERE: (1) SUPER FLAME RESISTANT NOMEX, (2) PBI (POLYBENZIMIDAZOLE) - SUPER FLAME RESISTANT NOMEX, (3) SUPER FLAME RESISTANT NOMEX CAMOUFLAGE AND (4) NOMEX III, TESTED AS A CONTROL. NOMEX III IS A 95/5% NOMEX-KEVLAR BLEND AND IS THE STANDARD SAGE GREEN 27P FLIGHT SUIT CURRENTLY BEING USE BY NAVY AND AIR FORCE. THE TESTS WERE CONDUCTED AT THE NAVAL AIR DEVELOPMENT CENTER'S FACILITY AND THE SUITS WERE SUBJECTED TO THREE SECOND EXPOSURES USING JP-4 FUEL. ONE OF THE CAMOUFLAGE SUITS WAS TESTED AT FOUR SECONDS. (Keywords)

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The Authors

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INTRODUCTION

Reported here are the results of fire pit tests of several advanced versions of Nomex and PBI (Polybenzimidazole) known for their fire resistance. These materials are designed to improve the lot of service personnel in overcoming the dangers of fire.

MATERIALS

The four materials and the number of each tested were as follows: 1) Nomex, Solution-dyed, Sage Green, three suits; 2) Nomex Super Flame Retardant, Tan, three suits; 3) 20% PBI, 80% Nomex Super Flame Retardant, Sage Green, three suits and 4) A Super Flame Retardant Nomex version of the Battle Dress Uniform (BDU) with the camouflage print, four suits.

At the NAVAIRDEVCEN facility, test specimens are assigned an identification number which is composed as follows:

5 digits for material identification
4 digits for the Julian Date
1 digit for the year
3 digits for the serial number of the day
3 digits, a serial number assigned to the test

The four materials described above are encoded as follows:

NXSLD Nomex, solution- dyed, Sage Green

NXSFR Nomex super flame-retardant, Tan

PNSFR PBI-Nomex, super flame-retardant

NXCAM Nomex super flame-retardant, Camouflage

METHOD

The procedures are designed to simulate escape from fuel fires that might occur in combat that would result from the rupture and ignition of fuel cells. It is estimated that such a situation may require a few seconds and this test provided exposures of 3 and 4 seconds. Three assemblies of each of the four types of materials were tested at 3 seconds, the last camouflage assembly was tested at 4 seconds. The test procedures are described in detail in Ref. 1.

In the test, a fiber glass manikin (the department store type) was dressed with the clothing assembly. The dressed manikin was suspended under the arms by two hooks attached to the arm of a rotating jib crane. The path of the crane arm and the manikin during rotation took it over the fire pit for the exposure.

The fire pit is an open concrete basin measuring 25' x 20' and 8 inches deep. During testing it is filled with water. The surface of the water filled basin is provided with a grid, made of aluminum angle which divides the surface into 20 cells. A plumbing network at the bottom of the basin provides fuel to nozzles in the center of each of the cells. Fuel is pumped from supply tanks to each of the 20 nozzles and floated on the surface before ignition. Ignition is provided by four igniters located at each of the four corners of the pit. An air-propane mixture is ignited by spark plugs and the flames are directed toward the JP-4 fuel that is now on the surface of the water.

The facility is diagrammed in Fig. 1 which shows the location of the crane with respect to the fire pit. The velocity of the crane can be adjusted so that the manikin is in the flames for the required amount of time.

Operations take place behind an 8' high concrete block wall that is set back 3 feet along one side of the pit. The entire pit area is enclosed by a corrugated steel fence which is located about 20' from the edge of the pit on all sides. Heat from the burning fuel is such that the fence is too hot to touch during burning.

Two video cameras are set to view the manikin as it comes over the edge of the pit out of the flames. The locations of these cameras are shown in Figure 1. One has a wide angle lens, about 20 mm, and the other has a longer focal length so that the manikin image can fill the field. A third hand-held video camera is located on the operations side of the block wall. This camera views the manikin as it rounds the wall and passes out of view of the fixed cameras. These cameras provide a record of any burning of the assembly as it passes out of the flames and any after flaming that may occur. A fourth camera was placed on top of the fence to view the development of the fire after ignition. It is connected to a monitor that is behind the block wall.

A calorimeter[1] which measures the heat flux is mounted at the manikin's waist. It is planned to provide several more calorimeters in the future so that a more accurate estimate can be obtained of the heat flux experienced by the manikin. The calorimeter was read out on a millivolt recorder and the trace was integrated to obtain heat flux.

Paper temperature sensors mounted on leather patches were placed at 26 locations on the manikin to determine the temperature rise at the surface: 10 on the torso, 8 on the arms and 8 on the legs. The sensors are silver and are marked with a temperature at which they will change color turning black. For these tests, the critical temperature was 250^0 F and they were evaluated for surface area according to the allocation of Hardy(1). as shown in Figure 2.

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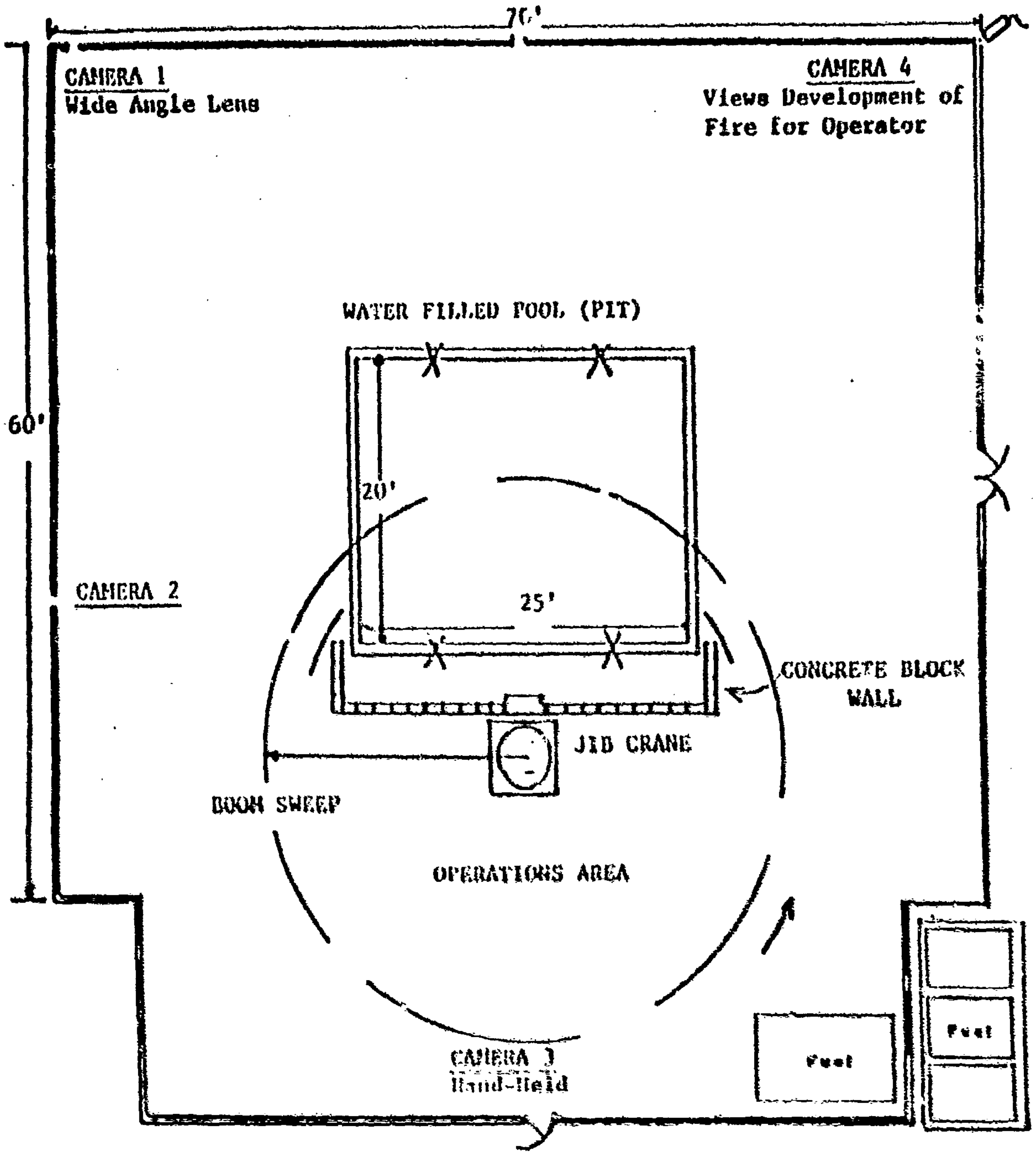
[1] HY-CAL Engineering, Santa Fe Springs, CA



NAVAIRDEVCEN Fuel Fire Test Facility

Figure 1. Diagram of the Fuel Fire Test Facility, reduced from a scaled drawing. The fuel is ignited by four air propane ignitors at Locations x. The compound is enclosed by a corrugated steel fence and the fire pit is located about 20' inside the fence on three sides. The 8' concrete block wall is shown on the fourth side. (See text)

PROCEDURE

Procedures can be derived from the description above. The manikin was sensored (paper sensors), then dressed in summer underwear (trunks and T shirt) and the test garment. Still photographs were taken and the manikin was placed on the crane arm and positioned. Cameras were adjusted for the day's testing, fuel was pumped into the pit and allowed to spread on the surface for about 10 sec., the ignition was activated and the fire was allowed to develop. Near maximum fire intensity the flux meter recorder and crane rotation were started. The crane controller had been previously set to give the correct exposure time of the manikin in the flames. The crane continued rotating until the manikin was over the distal edge of the pit at which time the controller was turned off. After the crane came to a stop, the manikin was removed for still photographs and examination of the temperature sensors. Any activated sensors were recorded and then replaced in preparation for another test.

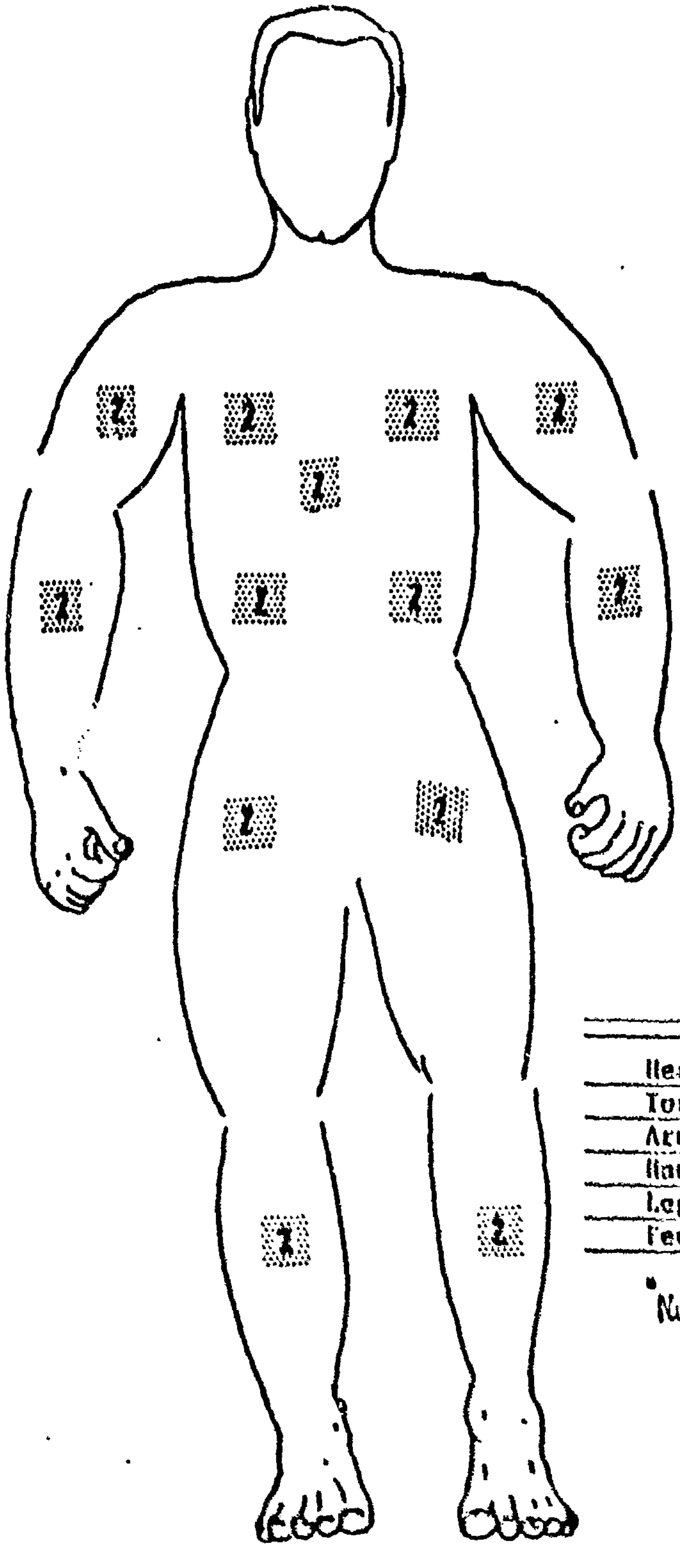
Three still color photographs of front, back and side views were taken of each garment assembly before and after the exposure.

RESULTS

The first garment to be tested, the Solution-dyed Nomex, is identified as follows:

NXSLD 7176 448
NXSLD 7176 452
NXSLD 7182 456

Figures 3, 4, and 5 show this flight suit before the exposure in front, back and side views. The still photographs taken after the exposure are shown in Figures 6, 7, and 8, front, back, and side views. These pictures show that there had been considerable shrinkage particularly in the legs.



	% Body Surface	No. Sensors
Head	7	4 *
Torso	35	10
Arms	14	8
Hands	5	4 *
Legs	32	8
Feet	7	2 *

*Not Used

Figure 2. The figure shows the location of the sensor patches on the manikin's surface. The number 2 represents one sensor patch on the front of the manikin and a corresponding sensor patch on the back.

Four to six inches of sock was showing above the boots, whereas before the test, the cuffs of the suit trousers were touching the boots. The ample amount of material that formed an irregular bubble in the back and wrinkles in the legs before burning had disappeared and the suit fit tightly after the test. The video tapes showed low, short purplish flames at the manikin's back during two of the tests (448 and 456), but they had disappeared by the time the manikin was over the edge of the pit. Also there was considerable smoking from the garment.

The surface of the manikin was evaluated according to the scheme of Hardy (2) in which body surface is allocated as follows:

Head	7%	Torso	35%
Hands	5%	Arms	14%
Feet	7%	Legs	32%

However, in these tests only the torso, arms, and legs were evaluated (total of 81%). The allocation of sensors is shown in Table I.

Table I. Allocation of Sensors by Body Region

Body Region	%of Total Body Surface	Number of Sensors	% of Body Surface per sensor
Torso	35%,	10	3.5%
Arms	15%	8	1.75%
Legs	32%	8	4.0%

Table II gives the percentage of surface burned for each region and the 'total body burned'(Total B.B.).

Two suits from which heat flux measurments are available show that they experienced hotter fires than any of the other suits in the 3 second tests. It is not possible to adequately explain these differences except to say that they reflect the limitations of our capability to monitor the fire.

TABLE II. PERCENT BODY BURNED AT 250 F FOR THE BURLINGTON TESTS

IDENTIFICATION	FLUX (CAL/CM2)	EXPO. SEC.	PERCENT BODY BURNED TORSO	ARMS	LEGS	TOTAL B.B.	DESCRIPTION
NXSLD 7176 448	7.62	3	7.00	10.50	24.00	41.50	NOMEX, SOLUTION-DYED, SAGE GREEN
NXSLD 7176 452	0.00	3	3.50	12.25	32.00	47.75	
NXSLD 7182 456	9.86	3	0.00	14.00	28.00	42.00	
NXSFR 7176 449	5.37	3	3.50	5.25	20.00	28.75	NOMEX, SUPER FLAME RETARD.,LIGHT TAN
NXSFR 7176 453	7.75	3	7.00	10.50	24.00	41.50	
NXSFR 7182 457	5.08	3	0.00	7.00	24.00	31.00	
PNSFR 7176 450	0.00	3	7.00	8.75	24.00	39.75	PBI/NOMEX, SUPER FLAME RETARD.SAGE GREEN
PNSFR 7182 454	6.19	3	7.00	5.25	20.00	32.25	
PNSFR 7182 458	6.77	3	0.00	5.25	20.00	25.25	
NXCAM 7176 451	0.00	3	0.00	3.50	20.00	23.50	NOMEX, SUPER FLAME RETARD. CAMOUFLAGE
NXCAM 7182 455	4.97	3	7.00	10.50	28.00	45.50	
NXCAM 7182 459	4.71	3	0.00	8.75	12.00	20.75	
NXCAM 7211 460	9.03	4	0.00	10.50	32.00	42.50	

One flux meter is probably not enough considering the randomness with which the fire burns. All three of the Solution-dyed Nomex suits were above 40% for total body burned averaging 43.75%.

The second garment to be tested, the Super-flame retardant Nomex, is identified as follows:

NXSFR 7176 449
NXSFR 7176 453
NXSFR 7182 457

The photographs before the exposure are shown in Figures 9, 10, and 11, front, back and side views. The still photographs after the exposure are shown in Figures 12, 13 and 14. The results from the temperature sensors can be seen in Table II. They show that these suits faired better than the previous group, in that the average total body burned figure was well below 40% at 33.75%. No burning was observed at the exit from the flames. There was shrinkage as shown in the Solution-dyed suits and in one test there was asmall, 1 inch hole burned through.

The PBI-Super flame retardant Nomex blend comprised the third garment to be tested and is shown in Figures 15, 16 and 17, front, back and side views. The photographs taken after the exposure are shown in Figures 18, 19 and 20. These photographs confirm shrinkage in the legs but not as much as in the Solution- dyed Nomex. There still are some wrinkles in the suit. These suits are identified as follows in Table II:

PNSFR 7176 450
PNSFR 7182 454
PNSFR 7182 458

Table II shows that the PBI-Nomex blend is a slight improvement over the Super-flame retardant Nomex, showing total body burned of 32.42%. There was no flaming seen in tapes from the two fixed cameras; there was smoke and comparatively less shrinkage shown on the video.

The last garment to be tested was made of Super flame retardant Nomex Camouflage identified as follows:

NXCAM 7176 451
NXCAM 7182 455
NXCAM 7182 459

and is shown in Figures 21, 22 and 23, front, back and side views. The photographs after the exposure are shown in Figures 24, 25 and 26. These photographs show that the Nomex camouflage appeared to be little affected by the exposure in spite of the fact that the camouflage print tends to obscure gross shrinkage. No flaming was seen in any of the 3 second exposures of this specimen. There was smoke and some shrinkage. The temperature effects are shown in Table II. Of the four types tested: NXCAM averaged the smallest percentage burns in torso and legs, while for the arms the percentage was intermediate among all four types. Overall the average NXCAM total percentage body burned was lowest, 29,92%. The worst case result is shown in Figures 27 and 28. This was NXCAM 7182 455 that had 45.5% body burned. There is more uniform shrinkage and more discoloration of areas in Fig 28, back view, manikin's left, that shows some general heating effects, a brownish discoloration covering the manikin's left torso, left buttocks and left leg.

At the outset of this 3 second series, it was decided to test an additional suit at four seconds of the type which resulted in the least percent body burned at three second tests. The winner was the Nomex Camouflage and the results of this test are shown in Figures 29, 30 and 31 for front, back and side views. There was some burning as described above in the

Solution-dyed Nomex but no after-flaming. At 9.03Cal/cm^2 this was the greatest burn as expected.

DISCUSSION

The fuel fire is a source of radiative and convective heat which is the threat against which clothing is meant to protect. However, the question raised in these tests is whether the body burns observed are a good measure of the protective qualities of the material from which the garment was fabricated. Examination of the analysis of body regions in Table II, the torso with the largest body surface area, 32%, is burned less frequently and less intensely when compared to the arms and legs. In fact, the legs receive the greatest amount of burns. The question arises as to whether torso and legs, for instance, receive systematic differences of radiative and convective heating. With the legs, there is the possibility that heat may rise up the trouser leg by convection and cause a more intense burn, something which would not occur with the torso. If this were to happen, the observations of burns for the legs would be partially due to radiation and also to convection because of the construction of the trousers being open at the bottom and allowing heat to rise.

Table III. Comparison of the Average Percentage Legs and and Total Body Burned.

	Legs (32%)	Total Body Burned (81%)	Legs/Total x 100
NXSLD	28% 3 sec	43.75%	64%
NXSFR	22% "	33.75%	65%
PNSFR	21% "	32.42%	64%
NXCAM	20% "	29.92%	66%
NXCAM	32% 4 sec	42.50%	75%

An argument can be made for this point of view in Table III above. Here the average percentage burned for the legs is tabulated with the total body burned from Table III, where 32% is maximum for the legs and 81% maximum for the total body. This analysis shows that total body burned varies directly with the average percentage burned for the legs. Leg percentages start with NXCAM at 20% and increase through NXSLD at 28% (+8%), while the respective total body burned percentages start at 29.92% and increase to 43.75% (+13.83%). The percentage contributed to the total is relatively constant at 65% for the 3 second tests, shown in the last column of Table III.

With the 4 second test, the percentage goes to 75%. So it would appear that trouser legs can create their own convection configuration, increasing heat to the legs. This tendency is also present with sleeves and the result is that open cuffs and sleeves give results worse than they would be if they were closed. Of course, the standard garments worn in the Services do have open cuffs and sleeves so their presence contributes some realism to the situation. It would be interesting, however, to test a garment in the two configurations with open and closed sleeves and cuffs as a means of determining differences in heating between the two conditions. Anticipating the answer to the question, it would be well if garments could be designed and fabricated, that would permit closed cuffs and sleeves while on duty.

In consideration of the Nomex Super-fire retardant camouflage material one has to turn to the only visible difference between it and the Nomex Super-fire retardant material and that is the camouflage print and its dye. The question arises as to whether the dye confers fire resistance and the answer from these tests appears to be in the affirmative. Considering that the dye is tightly bonded to the fiber and that heat must be absorbed and transmitted, it is an obstacle to the passage of heat. Further, there is a possibility that accompanying the absorption of heat there may be a heat absorbing reaction that would alter or decompose the dye in which case transmission of heat would further be inhibited. Simple sublimation in which heat would be absorbed in changing the state of the dye from solid to gas could also occur. This last hypothesis seems doubtful in these tests because the dye persisted through the tests with little change. Whether this speculation describes the actual case would require additional information (on the dye) and perhaps further tests.

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1. Kydd, G. H. and Marano, J. C. The NADC Fuel Fire Test Facility Procedure for Fire Pit Evaluation of the Thermal Protection Clothing Assemblies. Tech. Rpt. NADC-86016-60, Naval Air Development Center, Warminster, Pa. 1986.

2. Hardy, D. D. and Soderstorm, G. F. Heat Loss from the Nude Body and Peripheral Blood Flow at Temperatures of 22^{o} to 35^{o}C. Journal of Nutrition 16:493, 1938.

Figure 3. Front view of the Solution-dyed fligh' suit.

Figure 4. Back view of the Solution-dyed flight suit.

Figure 5. Side view of the Solution-dyed flight suit.

Figure 6. Front view of the Solution-dyed Nomex flight suit after a 3-second exposure.

Figure 7. Back view of the Solution-dyed Nomex flight suit after a 3-second exposure.

Figure 8. Side view of the Solution-dyed Nomex flight suit after a 3-second exposure.

Figure 9. Front view of the Super flame-resistant Nomex flight suit.

Figure 10. Back view of the Super flame-resistant Nomex flight suit.

Figure 11. Side view of the Super flame-resistant Nomex flight suit.

Figure 12. Front view of the Super flame-resistant Nomex flight suit after a 3-second exposure.

Figure 13. Back view of the Super flame-resistant Nomex flight suit after a 3-second exposure.

Figure 14. Side view of the Super flame-resistant Nomex flight suit after a 3-second exposure.

Figure 15. Front view of the PBI-Super flame-resistant Nomex flight suit.

Figure 16. Back view of the PBI-Super flame-resistant Nomex flight suit.

Figure 17. Side view of the PRI-Super flame-resistant Nomex flight suit.

Figure 18. Front view of the PBI-Super flame-resistant Nomex flight suit after a 3-second exposure.

Figure 19. Back view of the PBI-Super flame-resistant Nomex flight suit after a 3-second exposure.

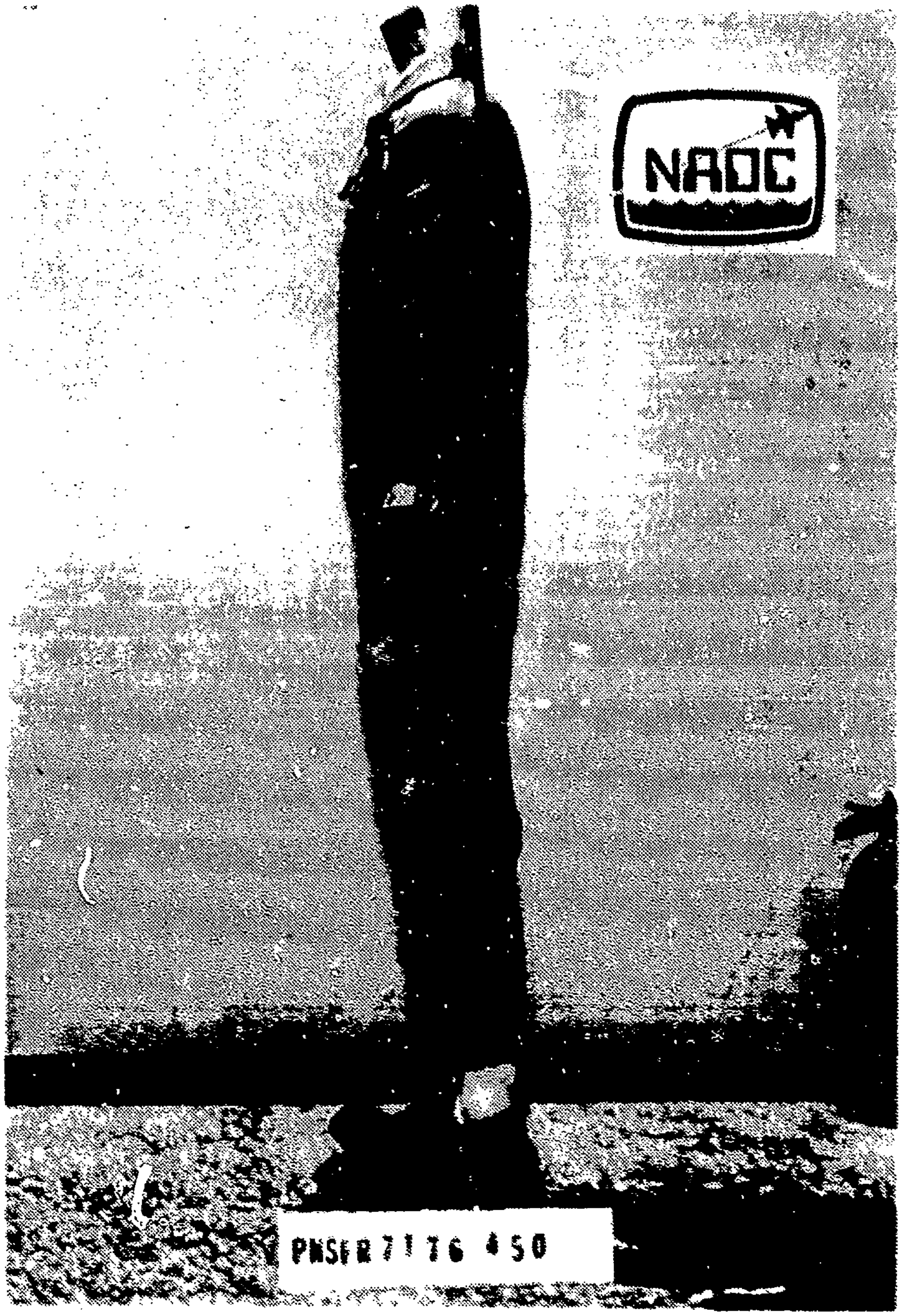

Figure 20. Side view of the PBI-Super flame-resistant Nomex flight suit after a 3-second exposure.

Figure 21. Front view of the Super flame-resistant Nomex Camouflage flight suit.

Figure 22. Back view of the Super flame-resistant Nomex Camouflage flight suit.

Figure 23. Side view of the Super flame-resistant Nomex Camouflage flight suit.

Figure 24. Front view of the Super flame-resistant Nomex Camouflage flight suit after a 3-second exposure.

Figure 25. Back view of the Super Flame-resistant Nomex Camouflage flight suit after a 3-second exposure.

Figure 26. Side view of the Super flame-resistant Nomex Camouflage flight suit after a 3-second exposure.

Figure 27. Front view of a second Super flame-resistant NOMEX Camouflage flight suit after a 3-second exposure.

Figure 28. Back view of a second Super flame-resistant Nomex Camouflage flight suit after a 3-second exposure.

Figure 29. Front view of the Super flame-resistant Nomex Camouflage flight suit after a 4-second exposure.

Figure 30. Back view of the Super flame-resistant Nomex Camouflage flight suit after a 4-second exposure.

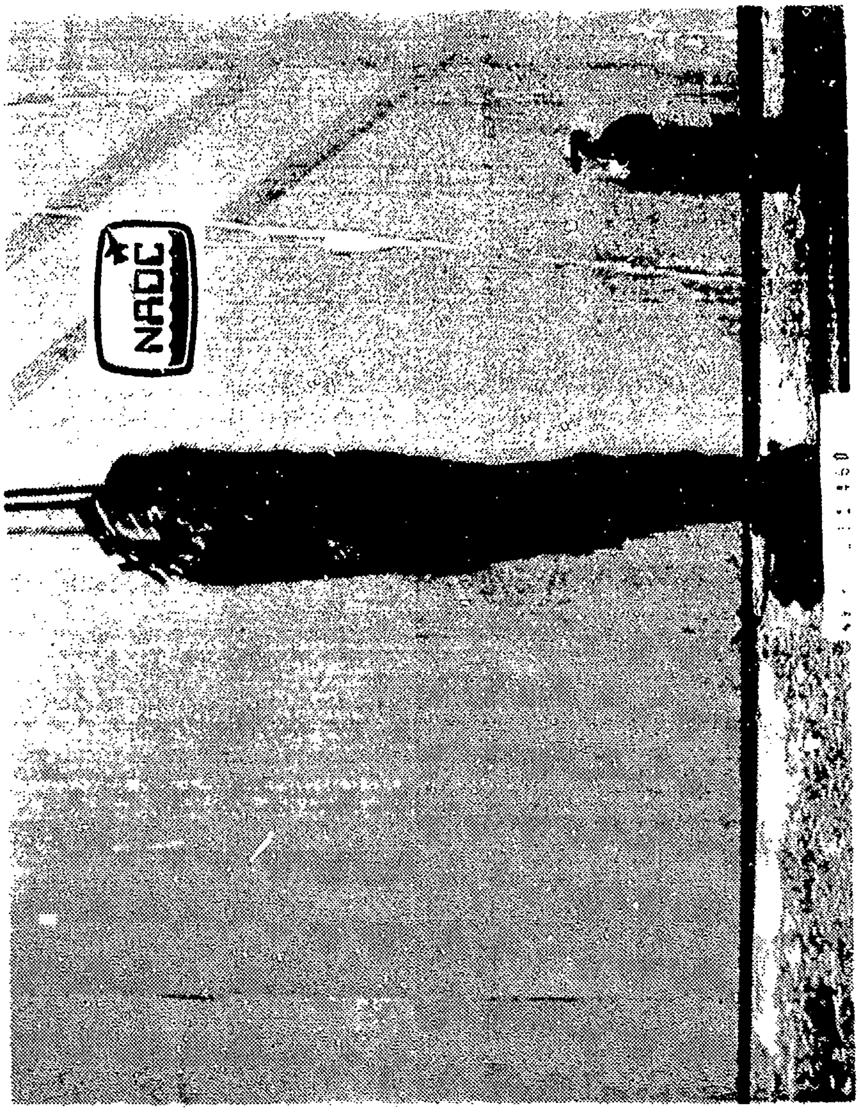

Figure 11. Side view of the Super flame-resistant Nomex Camouflage flight suit after a 4 second exposure

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